Supplement of Atmos. Chem. Phys., 22, 13303–13323, 2022
https://doi.org/10.5194/acp-22-13303-2022-supplement

Atmospheric Chemistry and Physics
Open Access
EGU

Supplement of

Interactive biogenic emissions and drought stress effects on atmospheric composition in NASA GISS ModelE

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Text S1

The figure shows the location of the MOFLUX (Missouri Ozarks) Ameriflux site located in central Missouri as a red diamond. The latitude and longitude of the MOFLUX site is 38.7441°N, 92.2000°W. The state of Missouri is displayed in green on a map of the continental United States, where state borders are shown in white.

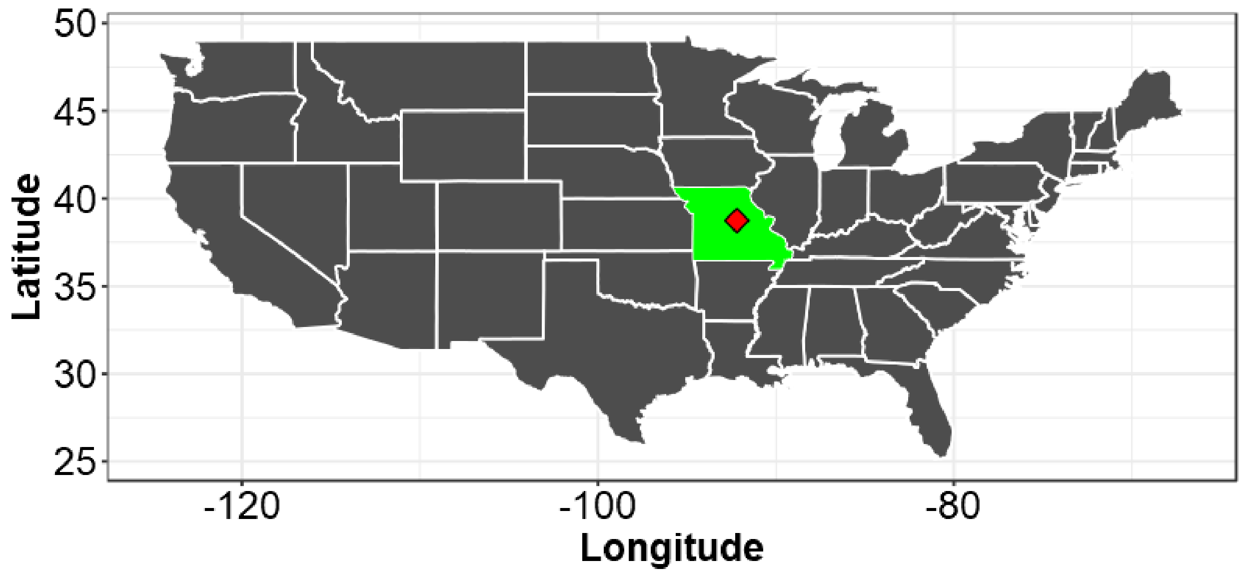

Figure S1: The figure shows the location of the state of Missouri shown in green, with a red diamond to indicate the MOFLUX Ameriflux site.

Text S2

The timeseries of daily averaged isoprene flux at the MOFLUX site (May-August 2011) top figure (a) and bottom figure (b) shows the daily biogenic isoprene flux from (May-September) 2012. Water stress is shown as a blue dotted line on the second y-axis, ranging from zero to one. A water stress value of one indicates no plant water stress and a low value indicates high plant water stress. The figure shows observations in black, the Default_ModelE simulation in red, the DroughtStress_MEGAN3_Jiang simulation in dark green, the MOFLUX_DroughtStress simulation in orange, and the DroughtStress_ModelE simulation in lime green. During 2011, it is clear all four simulations underestimate observed isoprene during a majority of the summer.

During later summer the model is clearly overestimating in 2011. In 2012, the summer is broken up into three main periods MAXVOC, Severe Drought, and Drought Recovery. During the MAXVOC period the model is underestimating, during the severe drought period the isoprene drought stress parameterizations are applied, and during the drought recovery period due to rising values of water stress the drought stress parameterizations stop reducing isoprene emissions.

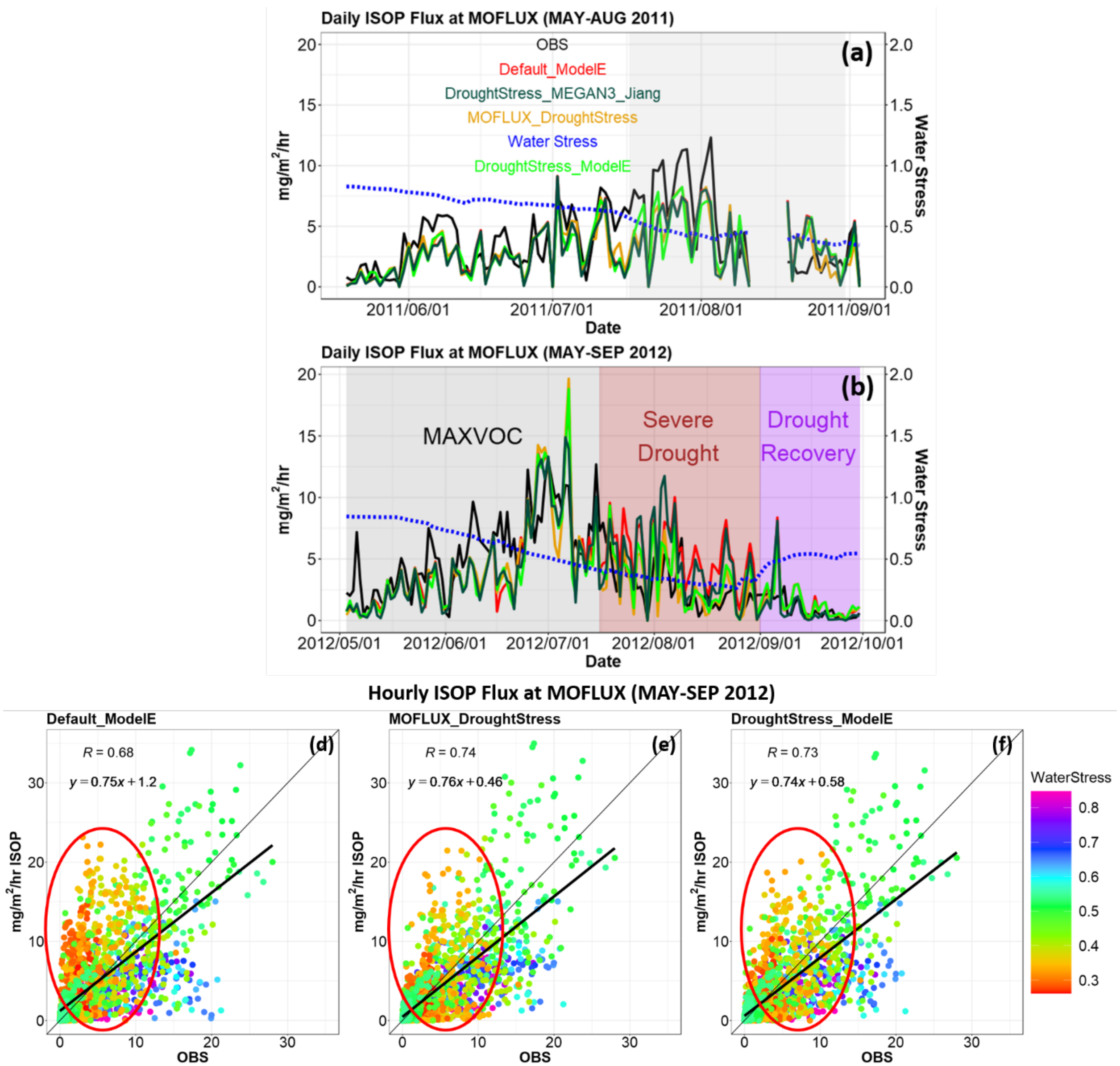

Figure S2: The timeseries of daily averaged isoprene flux at the MOFLUX site (May-August 2011) top figure (a) and bottom figure (b) shows the daily biogenic isoprene flux from (May-

September) 2012. This figure shows all four simulations described by Table 1 in the main text. This figure includes the timeseries for MOFLUX_DroughtStress which is not included in the main text as shown in orange. The left axis indicates isoprene emissions in $mg/m^2/hr$ of isoprene and the second y-axis indicates water stress which ranges from zero to one. The scatterplots (d-f) show the hourly comparison of observed isoprene to simulated during May-September 2012 at MOFLUX with the points color coded by water stress values. The panels (d-f) show Default_ModelE, MOFLUX_DroughtStress, and DroughtStress_ModelE, respectively.

Text S3

Figure shows the scatterplots (a-c) hourly and daily (d-f) averaged simulated isoprene emissions compared to observed for May-August 2011 at the MOFLUX site and the units are $mg/m^2/hr$ of isoprene. Default_ModelE's hourly correlation coefficient was 0.77, DroughtStress_MEGAN3_Jiang was 0.76, and DroughtStress_ModelE showed improvements with a correlation coefficient of 0.78. For all three online simulations there were only minor changes in slope and y-intercept. The daily correlation coefficient showed the largest change from 0.66 in the Default_ModelE to 0.68 in DroughtStress_ModelE. With 2011 being a less severe drought year, there was not expected to be large improvements in the relationship of simulated to observed.

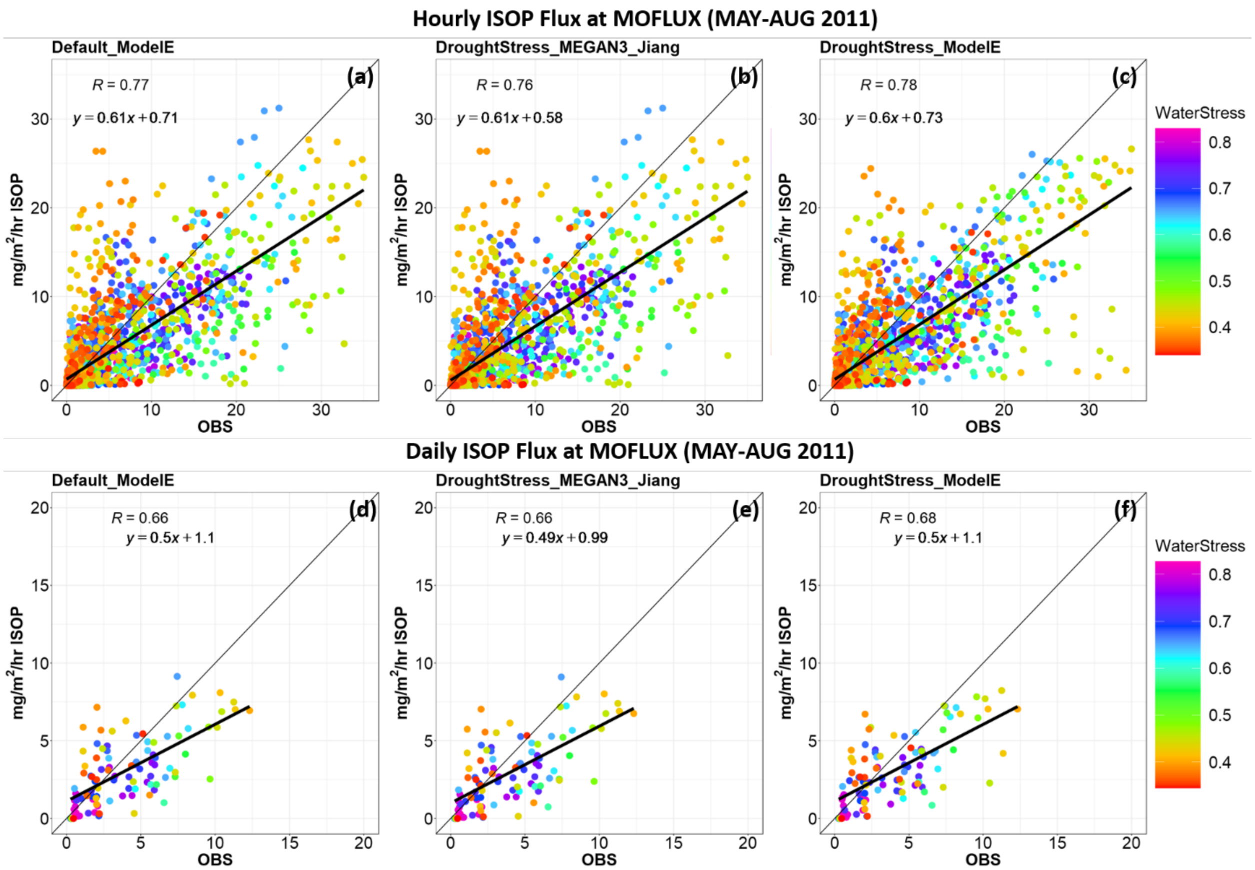

Figure S3: Figure shows the scatterplots (a-c) hourly and daily (d-f) averaged simulated isoprene emissions compared to observed for May-August 2011 at the MOFLUX site and the units are $mg/m^2/hr$ of isoprene. The points are color coded by water stress. The first column indicates Default_ModelE, the second column indicates DroughtStress_MEGAN3_Jiang, and the third column indicates the simulation DroughtStress_ModelE.

Text S4

The figure shows the diurnal cycle at the MOFLUX site for observed, Default_ModelE, MOFLUX_DroughtStress, and DroughtStress_ModelE. The top panel (a) shows the diurnal cycle from May-August 2011 and the bottom panel (b) shows the diurnal cycle from May-September 2012. For 2011, all simulations underestimate the diurnal cycle. For 2012, Default_ModelE overestimates the diurnal cycle, while shown in panel (b) DroughtStress_ModelE overlaps with observations during peak hours. ModelE does well in reproducing the diurnal cycle for 2012, but misses some characteristics of the shape in 2011.

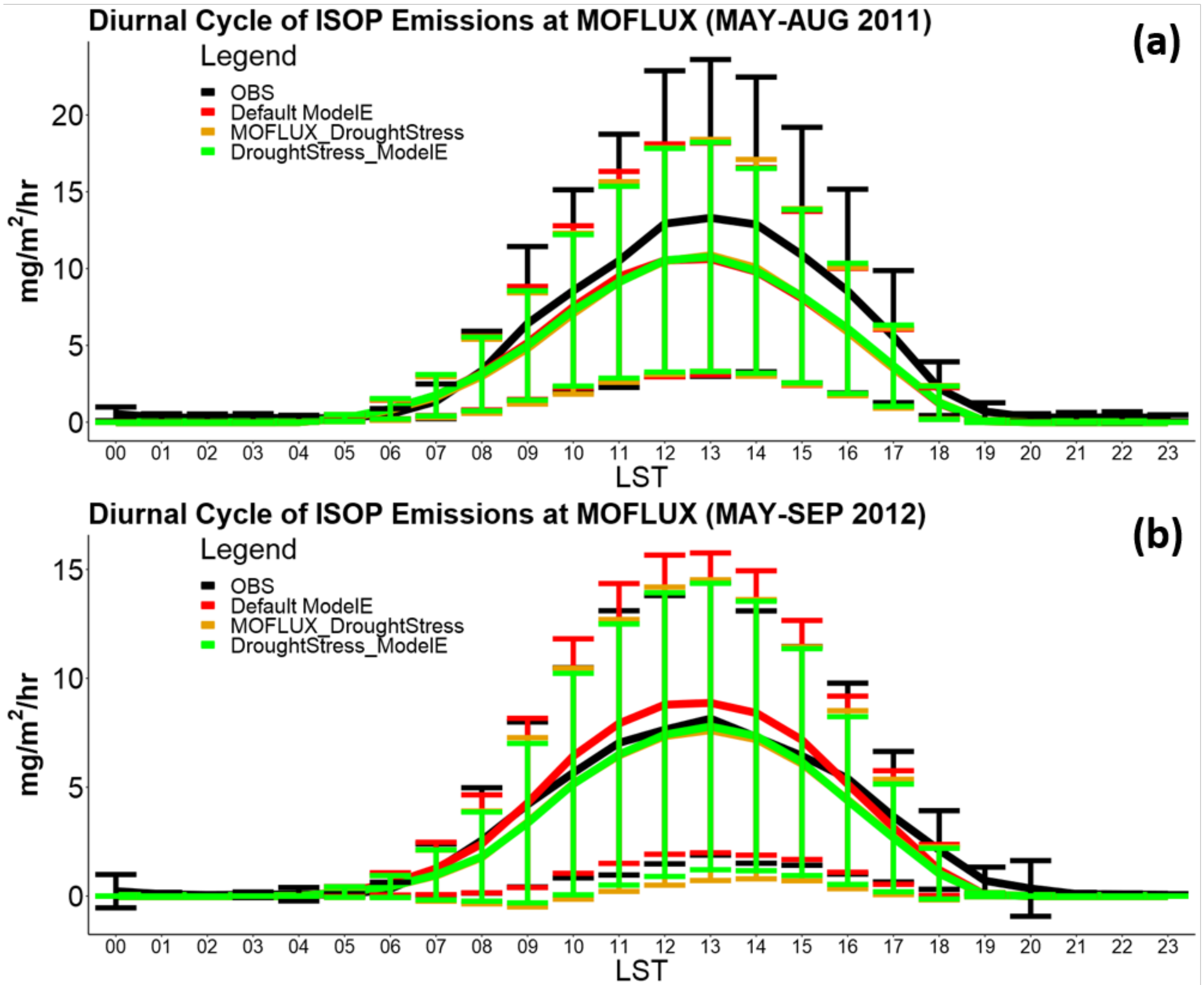

Figure S4: Diurnal cycle for May-August 2011 shown in (a) and diurnal cycle of isoprene emissions for May-September 2012 shown in (b). Black line indicates observations of isoprene emissions, red line is Default_ModelE without isoprene drought stress, orange line indicates MOFLUX_DroughtStress, and green indicates DroughtStress_ModelE. Full description of simulations in main text Table 1.

Text S5

Figure S5 shows the daily isoprene flux at MOFLUX from May-September 2012 for the simulations (a) Default_ModelE, (b) DroughtStress_MEGAN3_Jiang, and (C) DroughtStress_ModelE. In Default_ModelE the correlation coefficient is 0.64 and increases to 0.73 in DroughtStress_ModelE. Shown in panel (a) and (c) there is improvements in correlation slope and reductions in y-intercept indicating the isoprene drought stress parameterization improve daily simulations at the MOFLUX site.

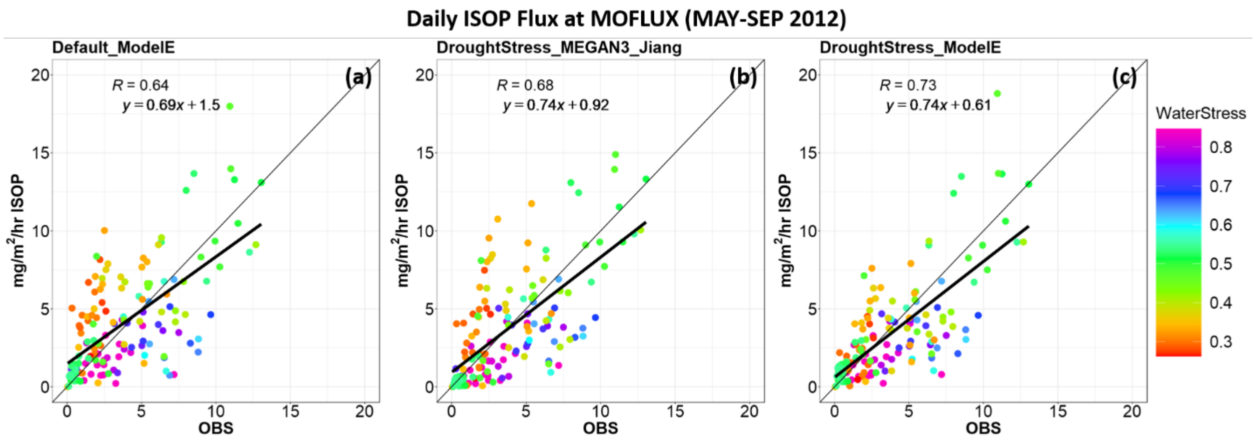

Figure S5: Shown are three scatterplots indicating the daily isoprene flux of simulated compared to observed at the MOFLUX site from May-September 2012. The first panel (a) indicates the Default_ModelE simulation, panel (b) indicates DroughtStress_MEGAN3_Jiang, and panel (c) indicates DroughtStress_ModelE. The points are color coded by simulated water stress. A zero to one line is also indicated on the plot as light grey while the regression is shown as a bolded black line.

Text S6

The map shows the location of four global isoprene emission hotspots. These four regions are selected to showcase the changes in isoprene emissions due to implementation of isoprene drought stress. The geographic regions are defined as East U.S. (Eastern U.S.) (65-105°W, 25-50°N), SA (Amazon) (40-80°W, 30°S-7°N), AF (Central Africa) (10-40°E, 15°S-10°N), and SE Asia (Southeast Asia) (100-150°E, 11°S-38°N).

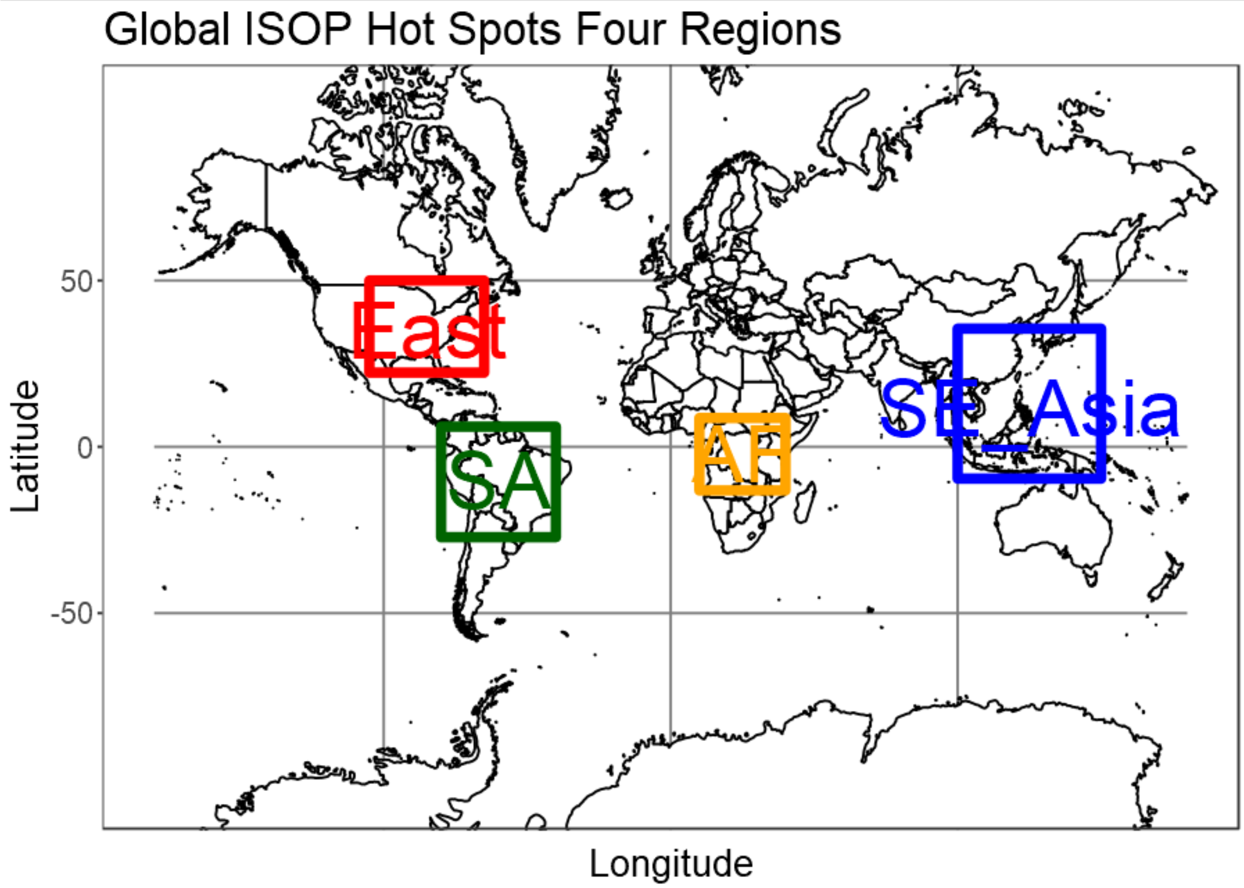

Figure S6: The four isoprene hotspots are depicted on the global map are Eastern U.S (East) shown by a red rectangle, Amazon (SA) shown by a green rectangle, Central Africa (AF) shown by an orange rectangle, and Southeast Asia (SE_Asia) shown by a blue rectangle.

Text S7

This map shows the geographic regions of the U.S. known as West (105-125°W, 25-50°N) and East (65-105°W, 25-50°N). The two regions are divided based on the demarcation line between when the magnitude of isoprene emissions and ΩHCHO rapidly decrease between Western and Eastern U.S.

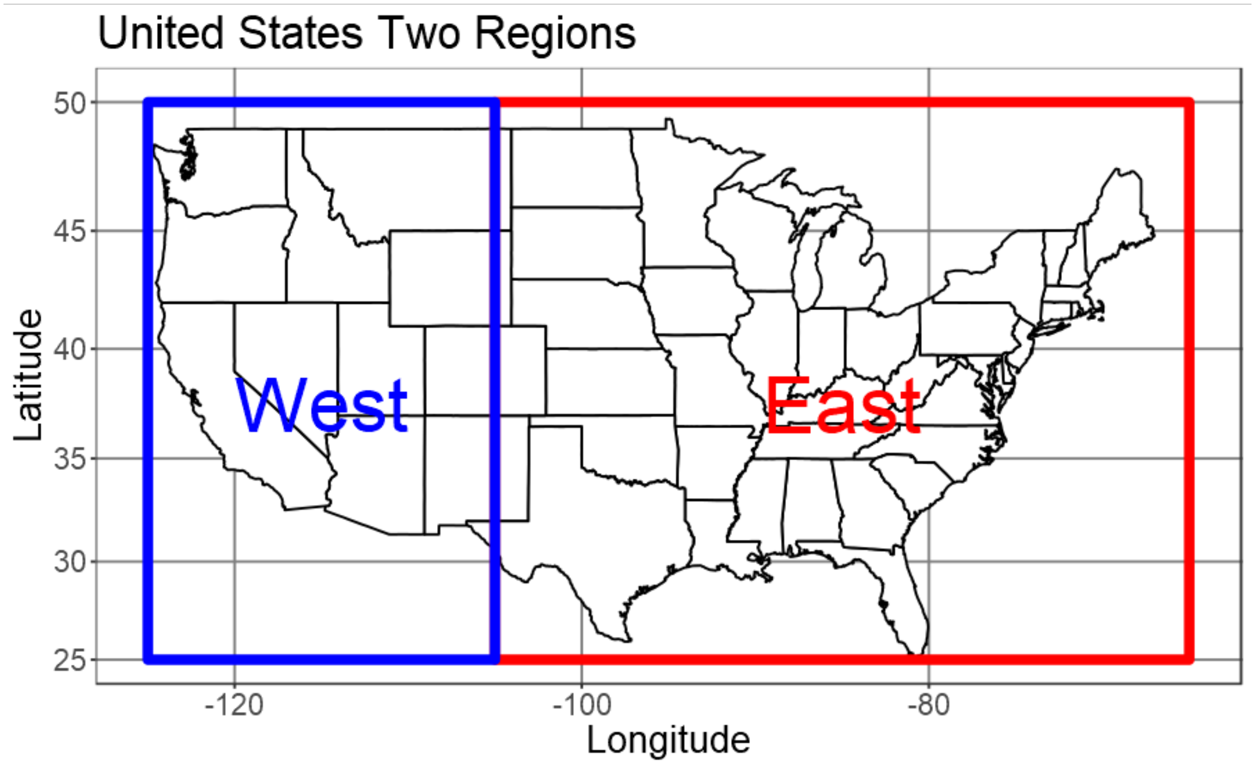

Figure S7: The map shows the region of West U.S. as a blue rectangle and East. U.S. as a red rectangle. The East geographic region includes the MOFLUX site.

Text S8

The shape of the fit for the MAXVOC, severe drought, and drought recovery period is shown as the distribution of daily averaged values in **Fig. R1** shown below. During the MAXVOC period the means for Default_ModelE and DroughtStress_ModelE are below observed shown by yellow diamonds. During the severe drought period DroughtStress_ModelE shown in green has a closer mean to observed shown in black indicating reduced emissions. During the drought recovery period there is little change in the distribution between Default_ModelE and DroughtStress_ModelE.

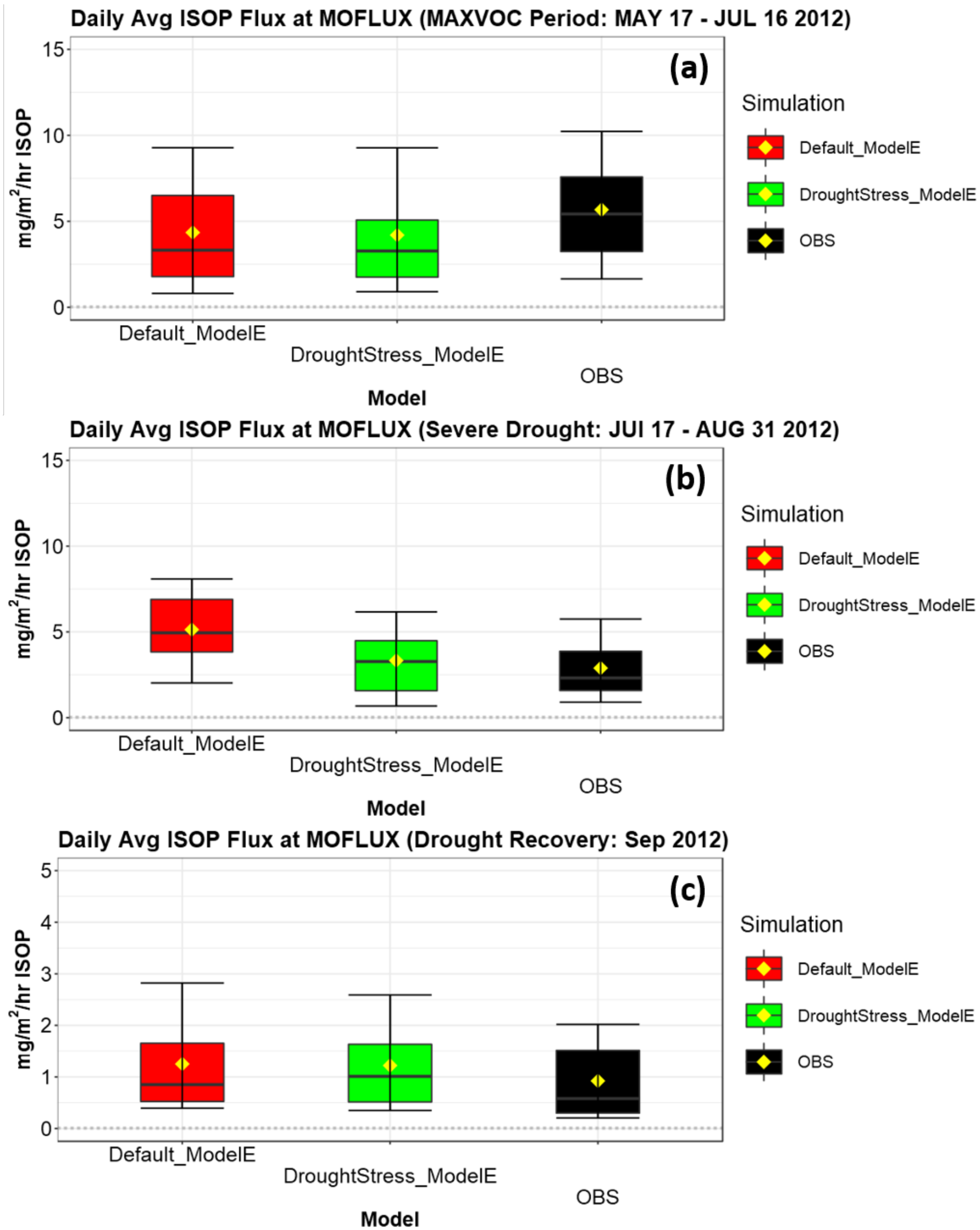

Figure S8: (a) boxplots to indicate the distribution of daily averaged isoprene emissions for the three simulations Default_ModelE shown in red, DroughtStress_ModelE shown in green, and observations show in black. (b) the distribution of isoprene during the severe drought and (c) the distribution during the drought recovery period with the averages shown by yellow diamond.

Text S9

Shown below is the timeseries of hourly peak isoprene for each day for the time period May-September 2012. Default_ModelE tends to underestimate the hourly peak of each day in the MAXVOC period. Default_ModelE for much of severe drought period is higher than observed compared to observed hourly peak for each day. DroughtStress_ModelE in green tends to reduce the daily peak and move it closer to observed during severe drought period. During drought recovery there is not much difference between Default_ModelE and DroughtStress_ModelE daily peaks.

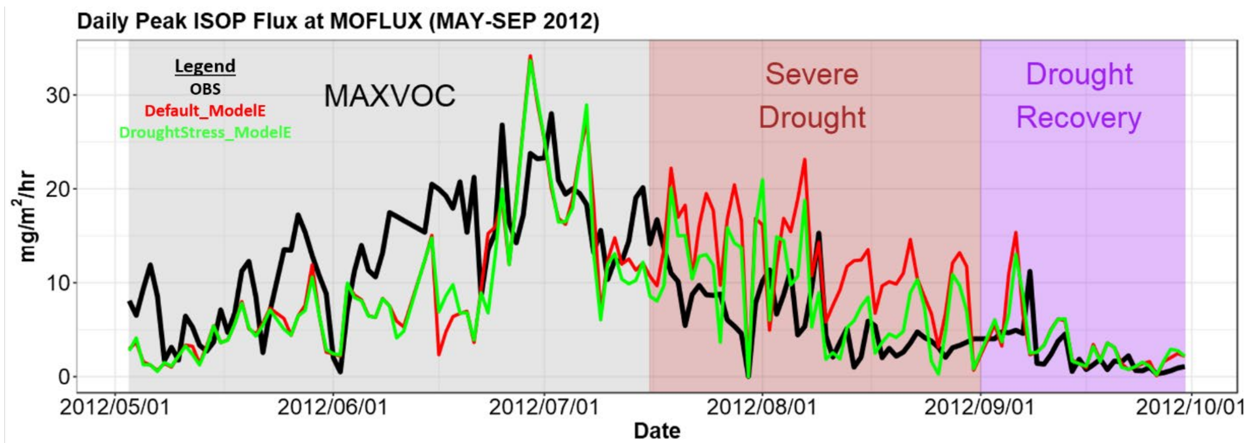

Figure S9: the timeseries shows the daily peak of isoprene emissions from May-September 2012 during the time periods MAXVOC, severe drought, and drought recovery. Observations are shown in black, Default_ModelE in red, and DroughtStress_ModelE shown in green.

Text S10

It is very hard to pinpoint what is making the model miss the daily peaks as there are too many uncertainties related to the MEGAN activity factors and the simplified canopy parameterization scheme used in our MEGAN implementation. For example, the model could be missing the peaks due to deposition values not being completely accurate, responsiveness of model to changing conditions could lag behind real time conditions, radiative properties, and chemistry could all contribute to the missing peaks. There is also the issue of comparing a site to a model grid which plays a factor. The model throughout May-September 2012 does reasonably capture the observed temperature quite well so its most likely not a temperature issue driving the missing peaks in daily isoprene as shown below.

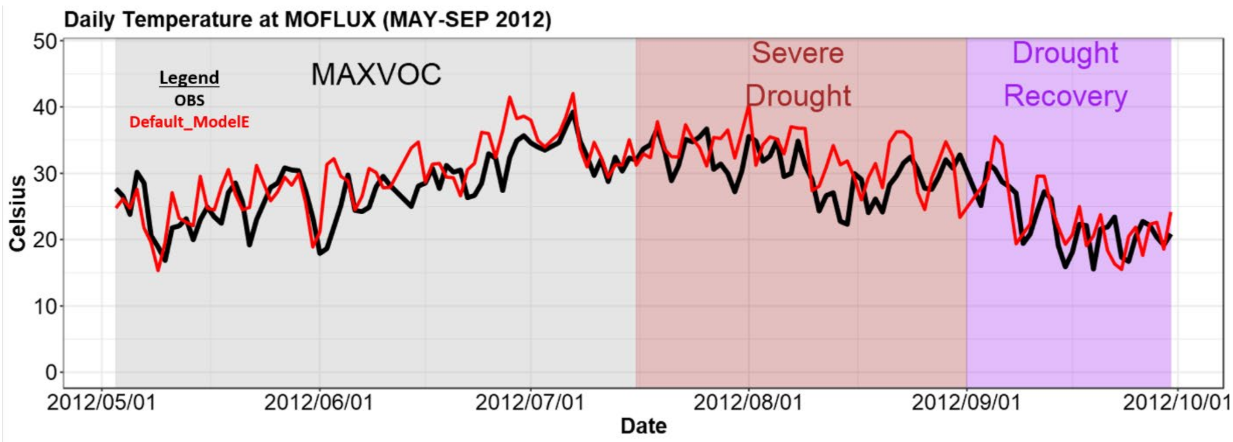

Figure S10: shows the timeseries of daily averaged temperature at MOFLUX site for May-September 2012 in Celsius. The observed temperature is shown in black and red shows Default_ModelE.

Text S11

We verified latent heat and sensible heat at the MOFLUX site and compared observed to simulated during May-September 2012. We found from May-September 2012 Default_ModelE does a reasonable job reproducing hourly sensible heat with a correlation coefficient (R) of 0.83 and slope of 1. For May-September 2012, Default_ModelE has a R of 0.60 and slope of 0.52 when comparing to observed hourly averaged latent heat as shown below in **Fig. R2**.

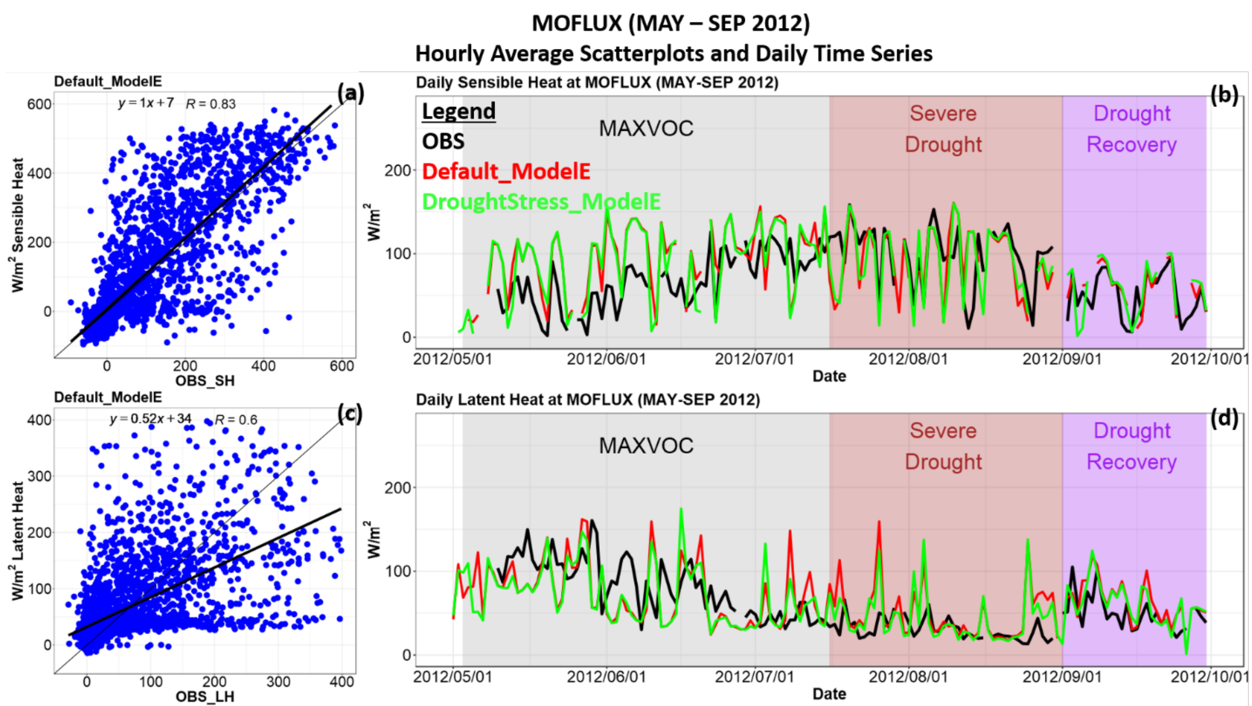

Figure S11: (a) shows the hourly averaged scatterplot comparing observed sensible heat (W/m2) to Default_ModelE for May-September 2012 at MOFLUX and (b) shows the daily averaged sensible heat timeseries comparing observed (black), Default_ModelE (red), and DroughtStress_ModelE (green) across the three periods of interest, MAXVOC (grey), Severe Drought (brown), and Drought Recovery (purple). (c) shows the hourly averaged latent heat (W/m2) of observed compared to Default_ModelE simulation for May-September 2012 at MOFLUX and (d) shows the timeseries of daily averaged latent heat.

Text S12

We verified LAI at the MOFLUX site during 2012 using the NOAA Climate Data Record AVHRR (Advanced Very High Resolution Radiometer) LAI dataset (Vermote 2019) that we averaged on a monthly scale and regridded from 0.05°x0.05° to match ModelE's horizontal resolution. The timeseries of monthly averaged LAI for 2012 at the MOFLUX site is shown below in panel (b). ModelE simulates LAI quite well compared to observed prior to MAY 2012. During the MAXVOC period, Default_ModelE overestimates LAI, which is also when it is underestimating isoprene. During the severe drought period when Default_ModelE is overestimating isoprene, we still see an overestimation of LAI during JUL and AUG. During the drought recovery period, Default_ModelE shows the same decreasing trend as observed. The overestimation and underestimation of LAI do not appear to be linked to the underestimation/overestimation of isoprene emissions in the model.

Variables shown below include (temperature, LAI, relative humidity, shortwave incoming solar radiation, CO_2 flux, vapor pressure deficit (VPD), and canopy conductance) are compared to observed when observations are available. The model on the monthly scale is able to capture temperature, relative humidity (RH), and incoming shortwave solar radiation compared to observed at the MOFLUX site reasonably well. The model does overestimate monthly CO_2 flux during the MAXVOC period and severe drought periods as shown (e). Observed measurements were not available for vapor pressure deficit (VPD) nor canopy conductance, but are shown to characterize model performance (f, g). It is interesting to note canopy conductance is highly responsive to beginning drought conditions during MAXVOC period and shows minimum during severe drought period with recovery at the end of the period. This responsiveness suggests it could be used as a variable for future drought parameterizations.

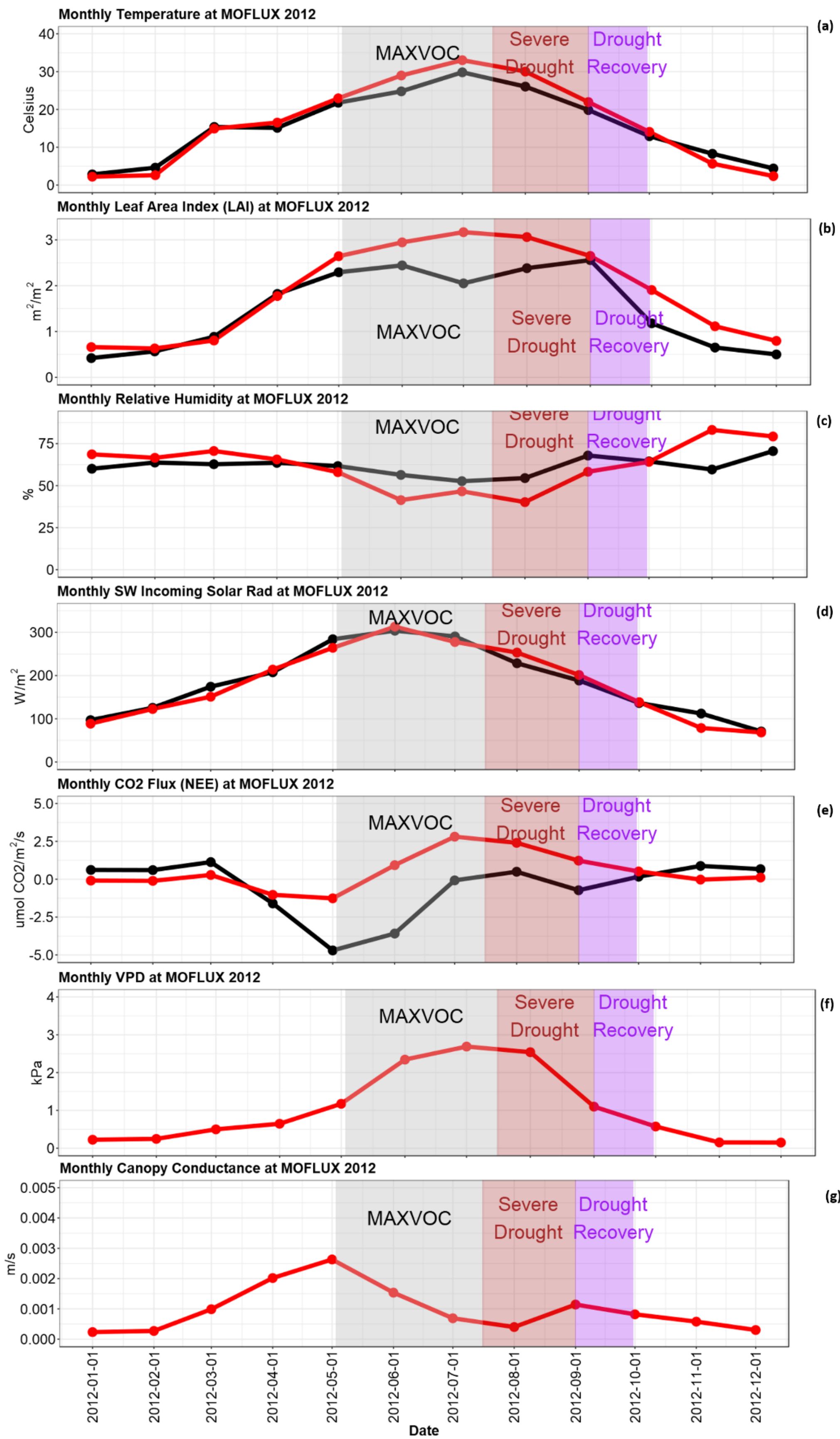
Monthly Temperature at MOFLUX 2012
Celsius
(a)
Monthly Leaf Area Index (LAI) at MOFLUX 2012
m^2/m^2
(b)
Monthly Relative Humidity at MOFLUX 2012
%
(c)
Monthly SW Incoming Solar Rad at MOFLUX 2012
W/m^2
(d)
Monthly CO2 Flux (NEE) at MOFLUX 2012
umol CO2/m^2/s
(e)
Monthly VPD at MOFLUX 2012
kPa
(f)
Monthly Canopy Conductance at MOFLUX 2012
m/s
(g)
MAXVOC
Severe Drought
Drought Recovery
2012-01-01
2012-02-01
2012-03-01
2012-04-01
2012-05-01
2012-06-01
2012-07-01
2012-08-01
2012-09-01
2012-10-01
2012-11-01
2012-12-01
Date

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Figure S12: monthly stacked timeseries of meteorological variables at MOFLUX during 2012: (a) temperature (Celsius), (b) LAI (m^2/m^2), (c) relative humidity (RH) (%), (d) shortwave incoming solar radiation (W/m^2), (e) CO_2 Flux (Net Ecosystem Exchange) (NEE) μmol $CO_2/m^2/s$, (f) vapor pressure deficit (VPD) (kPa), and (e) canopy conductance (m/s). Monthly averaged observed is shown in black for when observations are available and Default_ModelE simulated is shown as red. The periods denoted MAXVOC (grey), severe drought (brown), and drought recovery (purple) are labeled on the timeseries.

Text S13

Shown below are the scatterplots of hourly isoprene at MOFLUX during the 2012 severe drought period, with the points color coded by water stress values for the simulations, Default_ModelE, DroughtStress_MEGAN3_Jiang, and DroughtStress_ModelE. When comparing the severe drought period in Default_ModelE to DroughtStress_ModelE we do not see an improvement in R despite seeing large improvements of mean bias, but we do see a decreasing slope and lower y intercept. Default_ModelE during severe drought period has a mean of 5.10 $mg/m^2/hr$ ISOP and DroughtStress_ModelE has a mean of 3.31 $mg/m^2/hr$ of ISOP. Shown below in the scatterplots is reduction and tighter fit around 1:1 line. When we examine the daily correlation coefficient the R increases from 0.40 (Default_ModelE) to 0.48(DroughtStress_ModelE) for the severe drought period.

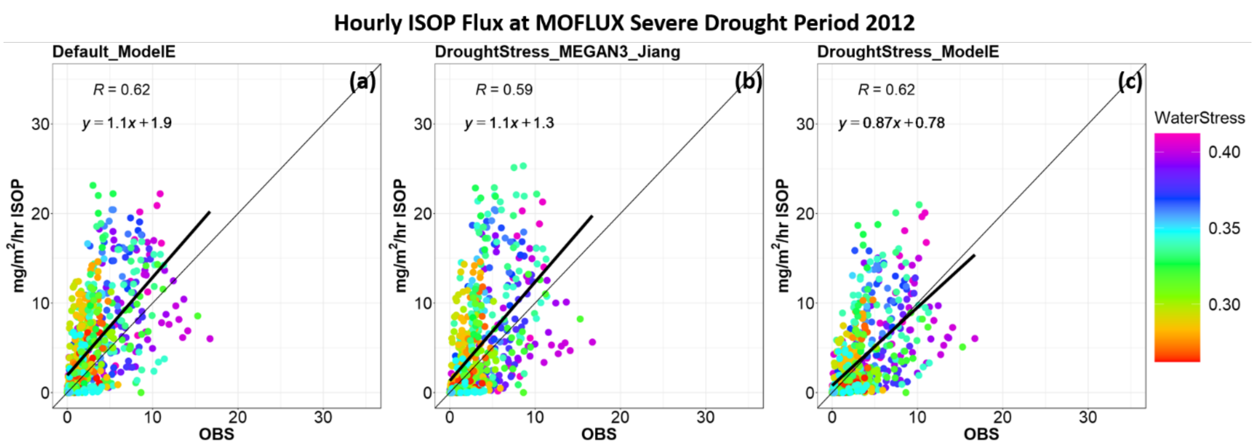

Figure S13: reports the metrics comparing observed hourly isoprene at the MOFLUX site during the severe drought period of 2012 to simulated isoprene (LST). (a) Default_ModelE, (b) DroughtStress_MEGAN3_Jiang, and (c) shows DroughtStress_ModelE with points color coded by the value of water stress.

Text S14

Shown below is monthly averaged simulated (Default_ModelE) soil moisture by layer. The upper layers (layers 1-4) show the largest response to beginning drought conditions in MAXVOC period with decreasing soil moisture. The severe drought period continues this behavior with decreasing soil moisture, while the drought recovery period shows an increase in soil moisture due to precipitation events at the end of August. The lower layers (5-6) show the least response in soil moisture with nearly linear behavior.

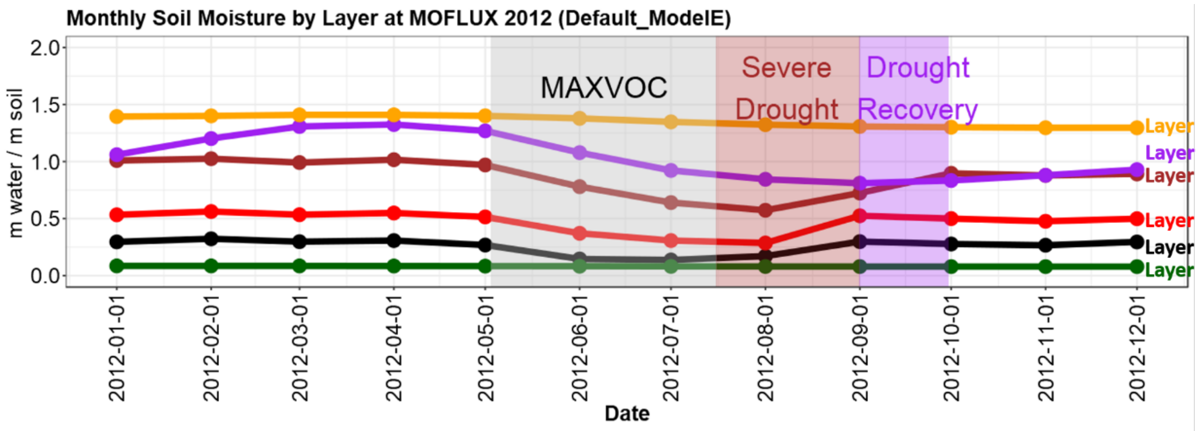

Figure S14: monthly averaged soil moisture for the individual layers of the soil during 2012. Layer 1 (black), layer 2 (red), layer 3 (brown), layer 4 (purple), layer 5 (gold), and layer 6 (green).